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USE OF NUCLEAR POWER SOURCES IN OUTER SPACE

Working paper submitted by the Russian Federation

In order to solve the problem of radiological safety of spacecraft carrying nuclear power sources (NPSs), it is important to study collisions of spacecraft carrying NPSs with space debris.

Bearing in mind the view of the Subcommittee regarding the need for detailed investigation of the problem of collisions between NPSs and space debris and for publication of the results of such investigations, the Russian Federation is submitting a working paper giving the results of calculations carried out in 1992 in the continuation of work done in 1991 under the Federation's overall programme to investigate the safety of space NPSs.

The paper considers possible collisions with space debris by the nuclear power reactors (NPRs) launched into space between 1970 and 1988 and located in orbits of 700-1,000 km.

Collision conditions were selected for the collision of a fuel element assembly with space debris in the form of steel fragments with a mass ranging from 0.25 kg and a linear dimension of 4 cm to a mass of 4.1 kg and a linear dimension of 10 cm. A study was made of the numerical modelling of a one-dimensional impact load applied to the laminated structure of a fuel element assembly consisting of 37 cylindrical fuel elements with annular beryllium reflectors and uranium-molybdenum alloy fuel pellets. The impact of fragments with a mass ranging from 0.25 kg to 4.1 kg and a velocity of 7.5 km/sec on the fuel element assembly was calculated. The initial parameters for the trajectory of the fuel element assembly before the collision were taken from data for the Cosmos-1900 satellite.

It was assumed in the calculations that, at the moment of collision, the fuel element assembly (target) and the debris (striker) are travelling at identical velocities at an angle of 90 degrees; i.e., the striker and the target are moving in orbits perpendicular to each other and the impact is directed along the longitudinal axis of the fuel element assembly.

The collision of a fuel element assembly with a 0.25-4.1-kg fragment of debris (striker) may be expected to cause disintegration of the fuel element assembly (target) into fragments with a mass of 0.1-1.3 kg (steel structural components), 0.04-0.3 kg (fuel pellets) and 0.056 kg (beryllium reflectors).

Given the limitations of the single numerical model selected at this stage of the research, the rates of deceleration in the direction of travel of the target remain unknown. These rates are assumed to represent a 50 per cent reduction compared with a perfectly elastic impact, and range from 35 m/sec for a striker with a 0.25-kg mass to 580 m/sec for a striker with a 4.1-kg mass. Additional impulses in the direction of travel of the striker may range from 30 m/sec to 3,400 m/sec, which, depending on the sign of the impulse, may significantly change the lifetime of the fragments of the target.

The change in flight trajectory parameters and in the lifetime of the fragments of the fuel element assembly after impact were calculated for the atmospheric model GOST 25645.115-84, which applies in the Russian Federation, with an average solar activity index of 106 and an average geomagnetic perturbation index of 2.667.

The lifetime of the fragments of the fuel element assembly ranges: for the steel structural components, from 100 to 10 years at 0-degree angles of entry into the atmosphere; for the fuel pellets, from 670 years at 0-degree angles of entry to 20 minutes at 1-degree to 8-degree angles of entry; for the beryllium reflectors, from 7.5 years to 40 minutes at 0-degree to 2-degree angles of entry.

Calculations of the aerodynamic characteristics of the fragments of the fuel element assembly, their movement dynamics around the centre of the masses during descent through the atmosphere, and their aerodynamic heating and disintegration, indicate that, with angles of entry into the atmosphere of about 0 degrees, the steel structural components are heated to melting point and disintegrate at great altitudes; the fuel-pellet fragments disintegrate fully at altitudes of 93-86 km with a combustion area covering 150-620 km; the beryllium reflectors disintegrate at altitudes of 78-52 km. At higher angles of entry into the atmosphere (1 degree to 8 degrees), the range of altitudes and the combustion area along the descent trajectory are lower and smaller. For example, a fuel pellet would be expected to disintegrate within a range of altitudes of 69-59 km with a combustion area of 66 km.

The results of calculations of the final particle size in the combustion of fuel-pellet fragments indicate that, at angles of entry into the atmosphere of about 0 degrees, the mean value of particle size is 200 microns and the range of particle size is 30-5,000 microns. At higher angles of entry into

the atmosphere (up to 8 degrees), the mean value of particle size is 100 microns and the range of particle size is 30-1,500 microns.

Assessment of the radiological consequences of the collision of NPSs with space debris should take into account the length of time the reactor will last after shut-down, i.e., the length of time it remains in orbit up to the moment of collision. The probability of collision of the NPS with space debris becomes significant when its lifetime exceeds 50 years. Consequently, the radiological consequences should be considered only for particles and fragments of the reactor fuel, since the induced movement of the reactor construction materials and the beryllium reflector cause virtual disintegration some 30-50 years after reactor shut-down.

Aerodynamic disintegration in the atmosphere of fragments of the beryllium reflectors will lead to the formation and fallout of particles resulting in a density of beryllium contamination of the soil that is lower than the natural beryllium content in the soil.

Aerodynamic disintegration of fuel-pellet particles with a lifetime of over 50 years may lead to the fallout of heavy fuel particles with a mass of up to 1.5 grams. The probability of the formation of such large particles is about 0.002.

Subsequent studies of issues involving the collision of NPSs with space debris envisage the development of a methodology for two-dimensional numerical modelling of the disintegration process using engineering functions for calculating the depth and diameter of the breakdown, the characteristics of secondary fragments and so on, based on experimental data.

Computer programs being developed for two-dimensional numerical modelling make it possible to define more precisely the dimensions of the fragments of the NPSs, the change in velocity of the fragments in the directions of travel of the striker and the target, and the change in the angle of orbit of the fragments. Forecasting of the navigational flight parameters of the fragments after impact, in combination with observational data, will make it possible to confirm the occurrence of a collision and to pinpoint the geographical coordinates of the point of entry into the atmosphere and the area of fallout.